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Further Study of the Gamma-Ray Bursts Duration Distribution

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Abstract. Two classes of gamma-ray bursts have been identified so far, characterized by durations shorter and longer than approximately 2 seconds. In 1998 two independent papers indicated the existence of the third class of the bursts roughly duration between 2 and 10 seconds. In this paper, using the full BATSE Catalog, the maximum likelihood estimation is presented, which gives a 0.5% probability to having only two subclasses. The Monte-Carlo simulation confirms this probability, too.

Key words. Gamma rays: bursts, theory, observations – Methods: data analysis, observational, statistical

1. INTRODUCTION

In the BATSE Current Catalog (Meegan, et al. 2001) there are 2702 Gamma-Ray Bursts (GRBs), of which 2041 have duration information. Kouveliotou, et al. 1993 have identified two types of GRB based on durations, for which the value of T_{90} (the time during which 90% of the fluence is accumulated) is smaller or larger than 2 s, respectively, and exhibits an acceptable bimodal log-normal ("two-Gaussian") fit. This bimodal distribution has been further quantified in another paper (Kouveliotou, et al. 1995), where a two-Gaussian fit was made, however the best parameters of the fit were published in McBreen, et al. 1994 and Koshut, et al. 1996.

Previously we have published an article (Horváth, 1998), where both two- and three-Gaussian fits were made using the χ^2 method, which gave a 99.98% significance the third Gaussian is needed. This is an agreement with the result of Mukherjee, et al. 1998, who used a multivariate analysis and found that the probability of existence of two groups, rather than three ones, is less than 10^{-4}. Hakkila, et al. 2000c also confirmed this result by statistical clustering analysis. However, they suggested that the third group was caused by instrumental biases (Hakkila, et al. 2000a, Hakkila, et al. 2000b). Recently Balastegui et al. 2001 have applied automatic classifier algorithms and obtain three different classes of GRBs. Add also that the intermediate subgroup shows a remarkable angular distribution on the sky (Balázs et al. 1998, Balázs et al. 1999, Mészáros et al. 2000, Litvin et al. 2001).

Although the high probabilities for the occurrence of third (intermediate in duration) subgroup are suggestive, the existence of the third subgroup is a matter of debate. Hence further studies concerning this subclass are highly needed. In order to make further progress in quantifying this classification, one of the issues which needs to be addressed is an evaluation of the probabilities associated with the bimodal, or - in general - with the multimodal distribution. In this paper we take another attempt at the trimodal log-normal distribution of T_{90}, evaluating a new small probability of the assumption that the third subclass is a chance occurrence.

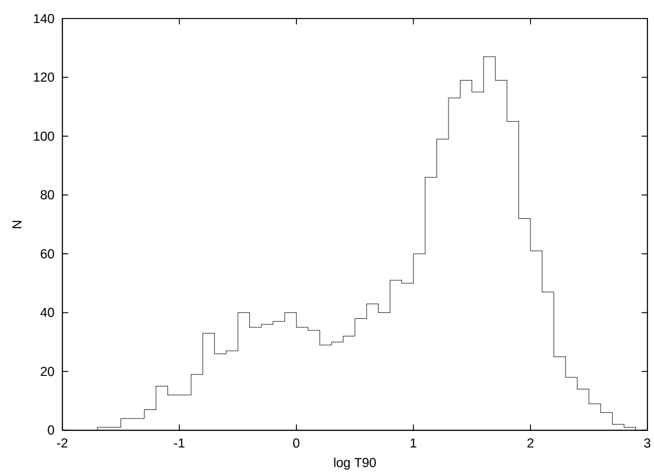

Fig. 1. Duration distribution of the observed BATSE bursts.

In Section 2 bi and a tri-modal log-normal fits have been made using the maximum likelihood method. In Section 3 a hundred Monte-Carlo simulations have been taken confirm the low probability. In Section 4 a triggering

Table 1. Two Gaussian fit of the GRBs duration distribution

	$Duration(logT_{90})$	$\sigma(logT_{90})$	w
short	−0.11	0.61	0.32
long	1.54	0.43	0.68

Averageduration($\log T_{90}$)standarddeviation(σ)andweight(w)ofthegroups.

systematic effect has been discussed. Finally the conclusions are given in Section 5.

2. FITS IN $\log T_{90}$

For this investigation we have used a smaller set of 1929 burst durations in the Current Catalog, because only they have peak flux information as well. We use the T_{90} measures provided in this data set. Figure 1. shows the distribution of $\log T_{90}$.

A fit to the duration distribution has been taken using a maximum likelihood method with the superposition of two log-normal distributions. This can be done by a standard search for 5 parameters with $N = 1929$ measured points (cf. Press et al. 1992; Chapt. 15). Both log-normal distributions have two parameters; the fifth parameter defines the weight (w_1) of the first log-normal distribution. The second weight is $w_2 = (1 - w_1)$ due to the normalization. Therefore we obtain the best fit to the 5 parameters through a maximum likelihood estimation (e.g., Kendall & Stuart 1976). We search for the maximum of the formula

$$L = \sum_{i=1}^{N} \ln\left(w_1 f_1(x_i, T_1, \sigma_1) + w_2 f_2(x_i, T_2, \sigma_2)\right) \tag{1}$$

where

$$f_k = \frac{1}{\sigma_k\sqrt{2\pi}} \exp\left(-\frac{(x-T_k)^2}{2\sigma_k^2}\right) \tag{2}$$

where T_k is the mean in log T_{90} and σ is the standard deviation. This fit gives us the best parameters of the two-Gaussian fit (Table 1.), which are very similar to previously published values (Horváth, 1998).

Secondly, a three-Gaussian fit has been taken with three f_k functions with eight parameters (three means, three standard deviations and two weights). For the best fitted parameters see Table 2. The best logarithm of the likelihood (L_3) is 12326.25 (Kendall & Stuart 1976). For two Gaussians the maximum of the likelihood was L_2=12320.11. According to the mathematical theory, twice the difference of these numbers follows the χ^2 distribution with three degrees of freedom because the new fit has three more parameters

$$2(L_3 - L_2) \simeq \chi^2_3, \tag{3}$$

The difference is 6.14 which gives us a 0.5% probability. Therefore the three-Gaussian fit is better and there is a 0.005 probability that it is caused by statistical fluctuation.

Table 2. Three Gaussian fit of the GRBs duration distribution

	$Duration(logT_{90})$	$\sigma(logT_{90})$	w
short	−0.25	0.53	0.26
long	1.55	0.42	0.68
intermediate	0.63	0.20	0.06

Averageduration($\log T_{90}$)standarddeviation(σ)andweight(w)ofthegroups.

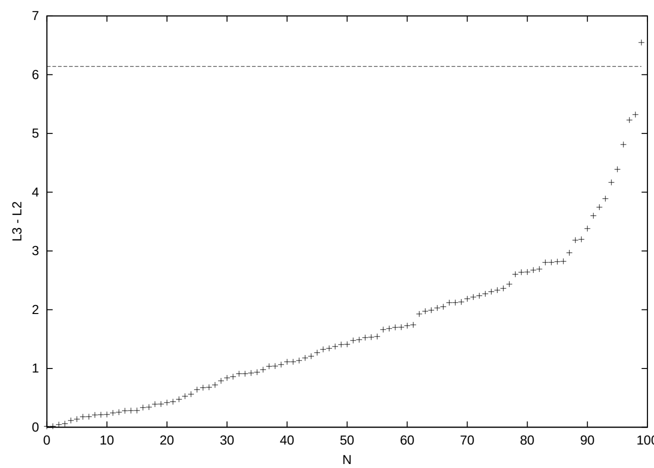

Fig. 2. Distribution of the MC simulated $L_3 - L_2$. L_3 is a likelihood with three-Gaussian and L_2 is a likelihood with two-Gaussian.

3. MONTE-CARLO SIMULATION

One can check this 0.005 probability using the Monte-Carlo (MC) simulation. Take the two-Gaussian distribution with the best fitted parameters of the observed data, and generate 1929 numbers for T_{90} whose distribution follow the two-Gaussian distribution. Find the best likelihood with five free parameters (two means, two dispersions and two weights; but the sum of the last two ones must be 1929). Secondly make a fit with three-Gaussian distribution (eight free parameters, three means, dispersions and weights). Take a difference between the two logarithms of the maximum likelihood, which gives one number.

This procedure is repeated 99 times and we have a hundred MC simulated numbers. Only one of these numbers is bigger than the value obtained from the BATSE data (6.14). The distribution of these differences are given in Figure 2. Therefore the MC simulations confirm the likelihood law statement and gives us a similar probability (1%) that the third group is a statistical fluctuation.

Also the population of the third group generated by MC simulations is far from the GRB third group population which is 6% (see Table 2.). The average of the fluc-

tuation population is 2,5% and only one of the hundred number is bigger than 6%.

4. SYSTEMATICS

In this section the possibility that the third intermediate subgroup is an instrumental effect is discussed. The BATSE on-board software tests for the existence of bursts by comparing the count rates to the threshold levels for three separate time intervals: 64 ms, 256 ms, and 1024 ms. The efficiency changes in the region of the middle area because the 1024 ms trigger is becoming less sensitive as burst durations fall below about one second. This means that at the "intermediate" timescale a large systematic deviation is possible. To reduce the effects of trigger systematics in this region we truncated the dataset to include only GRBs that would have triggered BATSE on the 64 ms timescale.

Using the Current BATSE catalog CmaxCmin table (Meegan, et al. 2001) we choose the GRBs, which numbers larger than one in the second column (64 ms scale maximum counts divided by the threshold count rate). This process reduced the bursts numbers very much, therefore unfortunately just 958 bursts satisfied the above condition.

We repeated the maximum likelihood test with these burst's durations. The computed probability is still below 1%. Therefore after eliminating some systematic effects, the third group is still statistically significant.

5. CONCLUSIONS

1. It is possible that the three log-normal fit is accidental, and that there are only two types of GRBs. However, if the T_{90} distribution of these two types of GRBs is log-normal, then the probability that the third group of GRBs is an accidental fluctuation is less than 0.5 %.
2. Therefore, statistically the third component existence is not questionable. However, the physical existence of the third group is still argued. The sky distribution of the third component is anisotropic as proven by Balázs et al. 1998, Balázs et al. 1999, Mészáros et al. 2000, Litvin et al. 2001. The logN-logS distribution is may also differ from the other group distribution Horváth, 1998. Opponently Hakkila, et al. 2000c believe the third statistically proved subgroup is only a deviation caused by a complicated instrumental effect, which can reduce some faint long burst's duration. This paper does not deal with the effect mentioned above, however the triggering systematic effects are examined and after that the third group is still statistically significant.
3. Therefore, this theme should be discussed in future papers to further elucidate the reality and properties of the third class.

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References

Balastegui, A., Ruiz-Lapuente, P. & Canal, R. 2001, MNRAS, 328, 283
Balázs, L.G., Mészáros, A. & Horváth, I. 1998, A&A, 339, 1
Balázs, L.G., Mészáros, A., Horváth, I. & Vavrek, R. 1999, A&A Suppl., 138, 417
Hakkila, J., et al. 2000a, Gamma-Ray Burst Fith Huntsville Symposium. Huntsville, Alabama. ed by R. M. Kippen, R. S. Mallozzi, and G. J. Fishman. AIP 526.
Hakkila, J., et al. 2000b, Gamma-Ray Burst Fith Huntsville Symposium. Huntsville, Alabama. ed by R. M. Kippen, R. S. Mallozzi, and G. J. Fishman. AIP 526.
Hakkila, J., et al. 2000c, ApJ, 538, 165
Horváth, I. 1998, ApJ, 508, 757.
Kendall, M. & Stuart, A. 1976, The Advanced Theory of Statistics (Griffin, London)
Koshut, T.M., et al. 1996, ApJ, 463, 570
Kouveliotou, C., et al. 1993, ApJ, 413, L101
Kouveliotou, C., et al. 1995, Third Huntsville Symposium on GRB. New York: in AIP Conference Proceedings 384, 84-89.
Litvin, V.F., Matveev, S.A., Mamedov, S.V. & Orlov, V.V. 2001, Pis'ma v Astronomicheskiy Zhurnal, 27, 495
McBreen, B., Hurley, K.J., Long, R. & Metcalfe, L. 1994, MNRAS, 271, 662
Meegan C. A., et al. 2001, Current BATSE Gamma-Ray Burst Catalog, on the Internet http://www.batse.msfc.nasa.gov/data/grb/catalog/
Mészáros, A., Bagoly, Z., Horváth, I., Balázs, L.G. & Vavrek, R. 2000, ApJ, 539, 98
Mukherjee, S., Feigelson, E.D., Babu, G.J., Murtagh, F., Fraley, C. & Raftery, A. 1998, ApJ, 508, 314
Press, W.H., Flannery, B.P., Teukolsky, S.A. & Vetterling, W.T. 1992, Numerical Recipes (Cambridge University Press, Cambridge)